

Efficacy of rhBMP-2-loaded self-setting calcium phosphate cement combined with nose ring drain technique in the treatment of gouty tophus with bone defect of the first metatarsophalangeal joint

Zejun Yu

Chongqing Orthopedic Hospital of Traditional Chinese Medicine Orthopedic Hospital, Chongqing University of Chinese Medicine

Jiangling Pan

Chongqing Orthopedic Hospital of Traditional Chinese Medicine Orthopedic Hospital, Chongqing University of Chinese Medicine

Xiaotian Xiong

Chongqing Orthopedic Hospital of Traditional Chinese Medicine Orthopedic Hospital, Chongqing University of Chinese Medicine

Qiang Liu

Chongqing Orthopedic Hospital of Traditional Chinese Medicine Orthopedic Hospital, Chongqing University of Chinese Medicine

Songchuan Su

Chongqing Orthopedic Hospital of Traditional Chinese Medicine Orthopedic Hospital, Chongqing University of Chinese Medicine

Ting Tong

804557350@qq.com

Chongqing Orthopedic Hospital of Traditional Chinese Medicine Orthopedic Hospital, Chongqing University of Chinese Medicine

Research Article

Keywords: rhBMP-2-loaded CPC, nose ring drain (NRD), first metatarsophalangeal joint, gouty tophus, bone defect

Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11091310/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.
[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Background:

This study aimed to compare the efficacy of recombinant human bone morphogenetic protein-2 (rhBMP-2)-loaded self-setting calcium phosphate cement (CPC) combined with the nose ring drain (NRD) technique versus conventional surgery with conventional drainage in treating gouty tophus with bone defect of the first metatarsophalangeal joint.

Methods:

This study was a retrospective study. A total of 40 patients with gouty tophus and bone defect of the first metatarsophalangeal joint were enrolled from the Department of Foot and Ankle Surgery, Chongqing Orthopedic Hospital of Traditional Chinese Medicine, between January 2019 and April 2026. The study group comprised 13 patients (20 feet) treated with rhBMP-2-loaded CPC combined with the NRD technique, while the control group comprised 27 patients (32 feet) treated with conventional surgery plus conventional drainage. C-reactive protein (CRP), erythrocyte sedimentation rate (ESR), and serum uric acid (UA) were assessed preoperatively and at 3 days postoperatively. Visual analogue scale (VAS) score, American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score, and incision healing time were evaluated preoperatively and at the last follow-up. Postoperative complications were also recorded.

Results:

Significant differences were observed between the two groups in CRP, ESR, VAS score, AOFAS score, incision healing time, incidence of delayed incision healing, and overall complication rate (all $P < 0.05$). No significant differences were found in UA, incidence of flap necrosis, or infection (all $P > 0.05$).

Conclusion:

The combined use of rhBMP-2-loaded CPC and the NRD technique for gouty tophus with bone defect of the first metatarsophalangeal joint can shorten incision healing time, reduce infection and reoperation rates, and shorten hospital stay. It may also relieve pain, improve joint function and quality of life, and create favorable conditions for bone regeneration. This approach appears clinically valuable and worthy of further promotion.

Introduction

Gout is an inflammatory arthritis driven by the deposition of monosodium urate crystals, with an onset occurring at progressively younger ages and a rising incidence ^[1]. Gouty tophus represents a hallmark

manifestation of advanced gout, most frequently involving the first metatarsophalangeal joint ^[2], and it not only erodes adjacent soft tissues but also invades underlying bone, resulting in extensive bone defects and joint destruction ^{[3][4][5]}, ultimately leading to irreversible functional impairment ^[6]. The management of gouty tophus with bone defect of the first metatarsophalangeal joint remains a formidable clinical challenge, as the available literature consists largely of case reports ^[7] that remain at an exploratory stage. Surgical intervention is still the cornerstone of treatment; however, it is associated with considerable surgical trauma and a range of postoperative complications, including skin ulceration, skin defects, persistent exudation, poor incision healing, necrosis, and infection ^[8]. At present, no surgical approach can completely eradicate gouty tophus, and after surgery, urate crystals, inflammatory necrotic tissue, and exudate continue to accumulate, creating an urgent need for safe, adequate, and effective drainage—a need that has become a focal point of current research. Consequently, an ideal therapeutic strategy should not only restore bone integrity, reestablish the length and height of the first ray, and recover weight-bearing function, but also provide reliable drainage to prevent wound infection. To date, no reports have described the combined use of rhBMP-2-loaded CPC and the NRD technique for treating gouty tophus. Building on successful applications of rhBMP-2-loaded CPC in bone defects caused by osteomyelitis ^{[9][10]} and of NRD in chronic infection and diabetic foot ^{[11][12]}, this study innovatively integrated the two modalities for the treatment of gouty tophus with bone defect of the first metatarsophalangeal joint. Encouraging clinical outcomes were achieved, and the detailed results are presented below.

Methods

Study Design and Patient Selection

This retrospective study was approved by the Ethics Committee of Chongqing Orthopedic Hospital of Traditional Chinese Medicine (approval number: GKYYIRB20240701).

Patients were eligible for inclusion if they met the following criteria: (1) gouty tophus confirmed by laboratory and imaging findings; (2) lesion located at the first metatarsophalangeal joint, with punched-out bone destruction and bone defect (Figure 1) confirmed by DR/CT; and (3) age $\geq$ 18 years.

Patients were excluded if they met any of the following criteria: (1) inability to tolerate or cooperate with surgery; (2) severe infection, vascular disease, or neuropathy; (3) segmental bone defect; or (4) incomplete follow-up data. No a priori sample size calculation was performed, as this retrospective cohort study enrolled all eligible patients. The 95% confidence intervals are presented to demonstrate the precision of the effect estimates.

The study group included 13 patients treated with rhBMP-2-loaded CPC combined with the NRD technique between January 2024 and April 2026. The control group included 27 patients treated with conventional surgery plus conventional drainage between January 2019 and December 2023.

Surgical Methods

Study group: implantation of rhBMP-2-loaded CPC combined with the NRD technique

After satisfactory anesthesia, the patient was placed in a supine position, and a tourniquet was applied at the base of the thigh. Following routine disinfection and draping, a longitudinal incision was made centered at the apex of the gouty tophus, exposing the lesion. Necrotic skin, fascia, and tendon were excised, and the gouty tophus was completely removed from the wound. Necrotic bone was resected, and the wound was copiously irrigated with normal saline. If hallux valgus was present, the conjoined tendon of the adductor hallucis, lateral joint capsule, and deep transverse metatarsal ligament were released through the same incision. A small curette was then used for repeated curettage and irrigation until bleeding from the cancellous bone was visible. Simple internal fixation was performed with Kirschner wires or by suturing the surrounding soft tissue. The rhBMP-2-loaded CPC (Figure 2) was implanted into the bone defect, and the soft tissue and skin edges were appropriately trimmed. Adequate hemostasis was achieved. Following the principle of “high entry and low exit,” drainage tubes (infusion tubes or blood transfusion tubes) were inserted. The tubes passed through the subcutaneous tissue, fascia, muscle layer, or bone, traversing the lesion. Two to three tubes formed one group. When the tubes exited the wound by 5–8 cm, they were ligated and fixed with silk sutures to form a ring-shaped nose ring drain (Figure 3). The number of drainage tube groups was determined by wound size, depth, and drainage difficulty. The joint capsule was then tightly sutured, the incision was closed in layers, and sterile dressings were applied and secured.

Control group: conventional surgery plus conventional drainage

After satisfactory anesthesia, the patient was placed in a supine position, and a tourniquet was applied at the base of the thigh. Following routine disinfection and draping, a longitudinal incision was made centered at the apex of the gouty tophus, exposing the lesion. Necrotic skin, fascia, and tendon were excised, and the gouty tophus was completely removed from the wound. Necrotic bone was resected, and the wound was copiously irrigated with normal saline. A small curette was used for repeated curettage and irrigation until bleeding from the cancellous bone was visible. Simple internal fixation was then performed with Kirschner wires or by suturing the surrounding soft tissue. The soft tissue and skin edges were appropriately trimmed, and adequate hemostasis was achieved. The joint capsule was tightly sutured, the incision was closed in layers, and a drainage strip was placed. Sterile dressings were then applied and secured.

Basic Treatment

Both groups received urate-lowering therapy. The target serum uric acid level was maintained below 300 $\mu\text{mol/L}$.

Outcome Measures

CRP, ESR, and serum uric acid (UA) were measured before surgery and at 3 days postoperatively. The visual analogue scale (VAS) score, American Orthopaedic Foot and Ankle Society ankle-hindfoot (AOFAS) score, and incision healing time were evaluated before surgery and at the last follow-up (3 months to 1 year postoperatively). Postoperative complications, including delayed incision healing, flap necrosis, and infection, were recorded. Delayed incision healing was defined as failure of healing with inability to remove sutures after 14 days postoperatively.

Statistical Analysis

All statistical analyses were performed using SPSS 26.0. Continuous data were first assessed for normality using the Shapiro-Wilk test. Normally distributed continuous data were presented as mean $\pm$ SD, and between-group comparisons were performed using the independent samples t-test. Non-normally distributed continuous data were presented as median (Q1, Q3); within-group comparisons were performed using the Wilcoxon signed-rank test, and between-group comparisons were conducted using the Mann-Whitney U test. Categorical data were presented as n (%). Because of the small sample size and unbalanced group sizes, Fisher's exact test was used for between-group comparisons of categorical data. The significance level was set at $\alpha = 0.05$, and $P < 0.05$ was considered statistically significant.

Results

A total of 40 patients were enrolled (Figure 4). The study group consisted of 13 patients, all of whom were male, with involvement of 4 left feet, 2 right feet, and 7 bilateral feet, accounting for 20 feet in total. Patient ages ranged from 18 to 72 years. The control group comprised 27 patients—26 males and 1 female—with 13 left feet, 9 right feet, and 5 bilateral feet, corresponding to 32 feet overall. Ages in this group ranged from 27 to 77 years. The duration of gouty tophus in both groups varied between 1 and 10 years. There were no statistically significant differences between the two groups in age ($t = -0.97$, $P = 0.340$), sex (Fisher's exact test, $P = 1.000$), affected side distribution (Fisher's exact test, $P = 0.093$), or disease duration ($Z = -0.582$, $P = 0.560$). The baseline characteristics were therefore balanced and comparable between the groups (Table 1).

Table 1. Baseline characteristics of subjects between the two groups

Characteristic	Study group (n=13)	Control group (n=27)	P value
Age, y	46.77±14.27	51.11±12.82	0.340
Male, n (%)	13 (100.0%)	26 (96.3%)	1.000
Affected side, n (%)			0.093
Left	4 (30.8%)	13 (48.1%)	
Right	2 (15.4%)	9 (33.3%)	
Bilateral	7 (53.8%)	5 (18.5%)	
Disease course, y	5.00(3.00, 8.50)	4.00(3.00, 6.00)	0.560

Unless otherwise noted, normally distributed continuous data are presented as mean ± SD; non-normally distributed continuous data as median (Q1, Q3); categorical data as n (%). $P < 0.05$ was considered statistically significant.

All continuous data were found to be non-normally distributed according to the Shapiro-Wilk test and were therefore expressed as median (Q1, Q3). Within-group comparisons between preoperative and postoperative values were conducted using the Wilcoxon signed-rank test, while between-group comparisons of improvement from baseline were performed using the Mann-Whitney U test. The significance level was set at $\alpha = 0.05$.

CRP and ESR levels decreased significantly after surgery in both groups (CRP: study group $Z = -3.110$, $P = 0.002$; control group $Z = -3.508$, $P < 0.001$; ESR: study group $Z = -3.181$, $P = 0.001$; control group $Z = -4.542$, $P < 0.001$). Notably, the magnitudes of improvement in both markers were significantly greater in the study group than in the control group (CRP: $Z = -2.816$, $P = 0.005$; ESR: $Z = -2.066$, $P = 0.039$). In contrast, UA levels showed no significant within-group or between-group differences (study group: $Z = -1.293$, $P = 0.196$; control group: $Z = -0.541$, $P = 0.588$; between groups: $Z = -1.011$, $P = 0.312$).

Both VAS and AOFAS scores improved significantly after surgery in the two groups (VAS: study group $Z = -4.005$, control group $Z = -4.986$, both $P < 0.001$; AOFAS: study group $Z = -3.926$, control group $Z = -4.941$, both $P < 0.001$). Interestingly, the control group exhibited a significantly greater reduction in VAS score ($Z = -2.378$, $P = 0.017$), whereas the study group achieved a significantly greater improvement in AOFAS score ($Z = -2.218$, $P = 0.027$). Furthermore, incision healing time was significantly shorter in the study group than in the control group ($Z = -2.792$, $P = 0.005$), indicating more rapid wound recovery in the study group.

The above efficacy-related indicators are summarized in Table 2.

Table 2. Comparison of observational indexes between the two groups at preoperative and postoperative stages

Index	Group	n	Preoperative	Postoperative	P (intra-group)	P (inter-group)
CRP,mg/L	Study group	13	35.56 (26.23, 52.95)	8.58 (6.17, 11.34)	0.002	0.005
	Control group	27	22.68 (10.73, 38.98)	7.88 (5.89, 20.39)	0.001	—
ESR,mm/h	Study group	13	66.00 (58.00, 73.00)	12.00 (8.00, 16.50)	0.001	0.039
	Control group	27	60.00 (40.00, 78.00)	18.00 (15.00, 30.00)	0.001	—
UA,umol/L	Study group	13	540.00(361.50, 608.50)	500.00 (394.50, 574.00)	0.196	0.312
	Control group	27	547.00(456.00, 584.00)	484.00 (419.00, 564.00)	0.588	—
VAS score	Study group	20	6.00 (6.00, 7.00)	1.00 (1.00, 2.00)	0.001	0.017
	Control group	32	6.50 (6.00, 7.00)	2.00 (1.00, 3.00)	0.001	—
AOFAS score	Study group	20	69.00 (57.50, 73.00)	86.50 (83.00, 94.00)	0.001	0.027
	Control group	32	67.00 (65.00, 75.00)	85.00 (82.25, 89.75)	0.001	—
Incision healing time, d	Study group	20	—	14.00(13.25,14.00)	—	0.005
	Control group	32	—	14.00(14.00,21.00)	—	—

Abbreviations: CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; UA, serum uric acid; VAS, visual analogue scale; AOFAS, American Orthopaedic Foot and Ankle Society ankle-hindfoot score.

P (intra-group): comparison of indexes within each group between preoperative and postoperative stages;*P* (inter-group): cross-sectional comparison between the two groups at the same surgical stage.Unless otherwise noted, non-normally distributed continuous data as median (Q1, Q3).*P* < 0.05 was considered statistically significant.

Categorical data on complications were summarized as n (%), and between-group comparisons of complication rates were conducted using Fisher's exact test. The incidence of delayed incision healing was significantly lower in the study group than in the control group (15.0% [3/20] vs. 46.9% [15/32]; *P* = 0.019). No cases of flap necrosis or infection were observed in the study group. In the control group, flap necrosis occurred in 1 case and infection in 2 cases; these complications were successfully managed

with secondary debridement and dressing changes, and all wounds subsequently healed. The incidence of flap necrosis was 0.0% (0/20) in the study group and 3.1% (1/32) in the control group, with no significant between-group difference ($P = 1.000$). Similarly, the incidence of infection was 0.0% (0/20) in the study group and 6.25% (2/32) in the control group, also showing no significant difference ($P = 0.517$). The overall complication rate was significantly lower in the study group than in the control group (15.0% [3/20] vs. 56.25% [18/32]; $P = 0.003$). Complication-related results are summarized in Table 3.

Table 3. Comparison of postoperative complications between the two groups

Complication	Study group (n = 20)	Control group (n = 32)	P value
Delayed wound healing	3 (15.0%)	15 (46.9%)	0.019
Flap necrosis	0 (0.0%)	1 (3.1%)	1.000
Surgical site infection	0 (0.0%)	2 (6.25%)	1.000
Overall complications	3 (15.0%)	18(56.25%)	0.003

Data are presented as n (%). Overall complications were defined as patients with at least one postoperative adverse event, with each patient counted only once. $P < 0.05$ was considered statistically significant.

Discussion

Gouty tophus represents a characteristic clinical manifestation of advanced or chronic gout and can give rise to severe complications, including skin ulceration, infection, joint deformity, and pathological fracture^[13]. Intra-articular deposition of urate crystals promotes the formation of gouty tophi, which are composed of monosodium urate crystals, inflammatory cells, and fibrous tissue. These tophi can inflict irreversible damage on bone, tendons, ligaments, and the joint capsule^[14].The first metatarsophalangeal joint serves as a critical weight-bearing structure of the foot, and its length and height are essential for maintaining the integrity and function of the foot arch^[15]. Gouty tophus can progressively destroy the first metatarsal, proximal phalanx, and metatarsophalangeal joint, resulting in bone defects and compromised joint stability, ultimately impairing weight-bearing capacity^[16]. The surrounding ligaments, tendons, and joint capsule may be eroded or ruptured, leading to joint dysfunction. In addition, skin ulceration and persistent exudation may develop, with the potential for secondary infection^[17]. Mild cases primarily affect appearance, whereas severe cases can lead to joint deformity and considerable functional impairment. In extreme cases, amputation may become necessary and can result in permanent disability.

Bone defects resulting from gouty tophus possess distinctive characteristics. First, the local milieu of chronic inflammation and elevated urate concentrations may suppress osteoblast activity. Second, the erosive nature of gouty tophus frequently produces irregular cystic defects, necessitating materials with

favorable plasticity and filling capacity. Third, affected patients often present with systemic metabolic abnormalities. For bone defects, autologous bone grafting has traditionally been regarded as the “gold standard.” Nevertheless, this approach is constrained by considerable limitations, including donor site morbidity, restricted graft availability, and prolonged operative time^{[18][19]}. rhBMP-2 is widely acknowledged as one of the most potent osteoinductive factors, capable of driving the differentiation of mesenchymal stem cells into osteoblasts and initiating bone regeneration^[20]. CPC exhibits favorable biodegradability, biocompatibility, and osteoconductivity^[21], and has been extensively applied in bone defect repair^[22]. The incorporation of rhBMP-2 into CPC carriers yields a composite biomaterial that combines osteoinductive and osteoconductive properties. Although direct evidence regarding the use of rhBMP-2/CPC for gouty tophus-associated bone defects remains limited, substantial evidence supports its application in maxillofacial surgery, oncology, spinal surgery, and orthopedic trauma for managing complex bone defects, including post-tumor resection defects, infectious bone defects, and traumatic bone defects^{[23][24][25][26]}. Consequently, this strategy holds considerable translational potential and may, in principle, offer an optimal reparative approach for the complex bone defects that remain after gouty tophus removal.

NRD, or the “nose ring drain,” is a continuous drainage technique in which at least two cylindrical infusion or blood transfusion tubes are passed through the subcutaneous tissue, fascia, muscle layer, or even bone. The tubes exit the skin and are secured in a ring configuration. Drainage is facilitated by the inter-tube spaces and by postoperative back-and-forth manipulation and irrigation of the tubes, enabling continuous flow from a high entry point to a low exit point across the lesion. NRD is readily accessible, cost-effective, technically straightforward, and provides reliable drainage, which has led to its widespread use in chronic complex infected wounds, degloving injuries, and diabetic foot^{[27][28]}. Urate crystals tend to adhere to the surrounding fibrous tissue and cartilage surface, rendering complete removal of gouty tophus practically impossible^[29]. Following surgery, urate crystals, inflammatory necrotic tissue, and exudate continue to accumulate, creating an urgent demand for safe, adequate, and effective drainage. Consequently, an optimal therapeutic strategy should not only address the bone defect, restore the length and height of the first ray, and reestablish weight-bearing function, but also provide sufficient drainage to effectively prevent wound infection. By combining rhBMP-2-loaded CPC implantation with the NRD technique, both bone repair and infection control can be achieved in the treatment of gouty tophus, offering a practical solution to these clinical challenges.

The present study demonstrated that the study group was significantly superior to the control group in reducing inflammatory markers, including CRP and ESR, as well as in shortening incision healing time. Previous research^[30] has suggested that urate crystal deposition in gouty tophus induces local tissue ischemia and a sustained inflammatory response, ultimately contributing to chronic non-healing wounds. Similarly, Kumar et al.^[31] identified delayed incision healing as the most common postoperative complication following gouty tophus surgery, and the complication profile observed in the present study is broadly consistent with that finding. Notably, the incidence of delayed incision healing was markedly lower in the study group than in the control group, and no serious complications such as flap necrosis or

infection occurred in the study group. The authors' analysis suggests that these favorable outcomes may be attributable to the following technical advantages of rhBMP-2-loaded CPC combined with the NRD technique. First, implantation of rhBMP-2-loaded CPC into the bone defect can effectively eliminate dead space. Second, compared with traditional drainage methods (e.g., rubber strips, drainage tubes, and vacuum sealing drainage [VSD]), the NRD is ring-shaped and through-and-through. The inter-tube spaces are less prone to obstruction, and the tubes can be manipulated back and forth and irrigated, allowing stepwise, small-volume, and progressive debridement—akin to a silkworm nibbling mulberry leaves. Because the tubes rarely become blocked, they enable continuous and adequate drainage and can remain in place for an extended period. This approach addresses the challenge of incomplete urate crystal clearance and persistent postoperative exudation. With regard to uric acid, no significant within-group or between-group differences in UA levels were observed. Although most gouty tophi were surgically removed, no appreciable short-term effect on UA was detected. Therefore, long-term urate-lowering therapy remains essential, with the target serum uric acid level maintained below 300 $\mu\text{mol/L}$ [32]. At the final follow-up, VAS scores had decreased and AOFAS scores had increased in both groups relative to preoperative values, indicating significant improvements in pain and function. These improvements may be attributed to the resolution of gouty tophi, reduced friction with footwear, and enhanced joint range of motion. The superiority of the study group may be further explained by its more favorable anti-inflammatory effect, earlier initiation of functional exercise, and the beneficial biomechanical properties of rhBMP-2-loaded CPC.

Historically, surgeons have been reluctant to perform complete removal of gouty tophus due to concerns over wound infection and uncertainties regarding subsequent bone reconstruction. However, the current strategy combining rhBMP-2-loaded CPC with the NRD technique offers several distinct advantages. The rhBMP-2-loaded CPC not only provides favorable biomechanical properties that facilitate early weight-bearing but also eliminates dead space following implantation. Meanwhile, the NRD technique ensures continuous drainage. Together, these complementary effects effectively address the dual challenges of infection control and bone reconstruction. Accordingly, we recommend that gouty tophus be excised as completely as possible during surgery. With respect to surgical timing, several authors [33][34] have advocated that patients with symptomatic gouty tophus should undergo active surgical excision to prevent irreversible joint damage. Our clinical experience aligns with this perspective. In addition, we emphasize that strict postoperative control of serum uric acid is essential to manage the disease at its source. Regarding bone defect management, we recommend that contained defects—characterized by preserved cortical support and limited loss of internal cancellous bone—be treated with rhBMP-2-loaded CPC for filling and structural repair. In contrast, when defects progress to a non-contained state, exhibit >50% circumferential cortical bone loss, or evolve into segmental defects, autologous bone grafting, the Masquelet technique, or Ilizarov bone transport should be considered.

Limitations

This study has several inherent limitations. First, as a retrospective investigation, it was inevitably constrained by the intrinsic shortcomings of retrospective data. During the long-term follow-up of the

study group treated with rhBMP-2-loaded CPC combined with the NRD technique, a number of patients were lost to follow-up owing to changes in contact information, missed outpatient appointments, or refusal to return for reevaluation because they reported no significant discomfort. In addition, incomplete clinical records further compromised data integrity. Consequently, the long-term healing status of the bone graft area could not be incorporated into the final statistical analysis. Second, the relatively small sample size may limit the generalizability and reliability of the findings. To strengthen the evidence base, future investigations should involve larger sample sizes, adopt multicenter randomized controlled trial designs, and extend the duration of follow-up. Such efforts would help further validate the current conclusions and enhance both the scientific robustness and clinical applicability of this approach.

Conclusion

In conclusion, the combined application of rhBMP-2-loaded CPC and the NRD technique for treating gouty tophus with bone defect of the first metatarsophalangeal joint can effectively shorten incision healing time, reduce the risks of infection and reoperation, and decrease hospital stay. Furthermore, this strategy can alleviate pain, enhance joint function and quality of life, and establish favorable conditions for bone regeneration. These findings indicate that the approach holds considerable clinical value and merits broader application.

Abbreviations

RhBMP-2-loaded CPC

recombinant human bone morphogenetic protein-2 loaded self-setting calcium phosphate cement

NRD

nose ring drain

ESR

erythrocyte sedimentation rate

UA

serum uric acid

VAS

visual analogue scale

AOFAS

American Orthopaedic Foot and Ankle Society ankle-hindfoot score.

Declarations

Ethics approval and consent to participate

This study was approved by the Medical Ethics Committee of Chongqing Orthopedic Hospital of Traditional Chinese Medicine, Chongqing, China (Approval No. GKYYIRB20240701). All procedures

involving human participants were performed in accordance with the 1964 Declaration of Helsinki and its later amendments, as well as relevant national guidelines and regulations. Written informed consent to participate was obtained from all participants.

Consent for publication

Written informed consent for publication was obtained from all participants whose wound images are included. The wound images are de-identified and do not contain identifying features or personal information.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by the Medical Research Project of Chongqing Municipal Health Commission (Grant No. 2025WSJK044).

Authors' contributions

Yu ZJ—data curation, writing original draft, and review and editing. Su SC—data analysis, and writing review and editing. Tong T—conceptualization, methodology, project administration, and writing review and editing. Pan JL—investigation, data curation, formal analysis. Xiong XT—investigation, data curation, performed patient follow-up. Liu Q investigation, and writing the original draft, performed patient follow-up. All authors have read and approved the manuscript.

Clinical trial number

Not applicable.

Acknowledgments

Not applicable.

Authors' information

¹Department of Foot and Ankle Surgery, Chongqing Orthopedic Hospital of Traditional Chinese Medicine [Orthopedic Hospital, Chongqing University of Chinese Medicine], Chongqing, China.

References

1. He Q, Mok TN, Sin TH, Yin J, Li S, Yin Y, Ming WK, Feng B, Global. JMIR Public Health Surveill. 2023;9:e45943. 10.2196/45943. . PMID: 37285198; PMCID: PMC10285625. Regional, and National Prevalence of Gout From 1990 to 2019: Age-Period-Cohort Analysis With Future Burden Prediction.
2. De Silva C, Díaz-Torné C, Gamble G, Horne A, Doyle A, Stamp LK, Dalbeth N. Mapping monosodium urate crystal deposition within metatarsophalangeal joints in tophaceous gout: a dual-energy CT study. Rheumatology (Oxford). 2025 Jun 24:keaf347. 10.1093/rheumatology/keaf347. Epub ahead of print. PMID: 40581776.
3. Hsu Y, Kung SC, Hsieh TJ, Tseng YH. Tophaceous gout of the knee: successful treatment with transarterial microembolization. Skeletal Radiol. 2026;55(1):239–43. 10.1007/s00256-025-05021-1. . Epub 2025 Aug 27. PMID: 40864294.
4. Okoroafor F, Ghazali S, Bhattacharyya D. Tophaceous spinal gout in a young man with complete spinal cord injury. BMJ Case Rep. 2023;16(8):e256360. 10.1136/bcr-2023-256360. . PMID: 37541694; PMCID: PMC10407413.
5. Hernández-Penagos D, Hilera-Camara JM, Franco-Gonzalez CD, Serrato-Rodriguez JJ, Tejero-Lopez JL, Vera-Aviles FA. Total Knee Arthroplasty for Severe Crystalline-Induced Arthropathy: A Case Report From a Third-Level Hospital. Cureus. 2025;17(4):e82462. 10.7759/cureus.82462. . PMID: 40385933; PMCID: PMC12085199.
6. Shetty PJA. Gouty Arthritis with Massive Tophaceous Deposits Involving Bilateral Metatarsophalangeal Joints, Surgical Treatment with Excision and Reconstruction - A Case Report. J Orthop Case Rep. 2025;15(4):69–73. 10.13107/jocr.2025.v15.i04.5448. . PMID: 40212496; PMCID: PMC11981492.
7. Żyluk A, Fliciński F. Outcomes of surgery for gouty tophi in the extremities. Pol Przegl Chir. 2022;94(5):18–22. 10.5604/01.3001.0015.7570. PMID: 36169580.
8. Kirschenbaum JD, Patel RG, Boylan MR, Virk MS. Operative management of gouty tophi in the region of the olecranon: a case series. JSES Int. 2022;6(3):550–4. PMID: 35572418; PMCID: PMC9091931.
9. MAHFOUZ H, MAHFOUZ H, FARII HA. Clinical outcomes, safety, and cost considerations of rhBMP-2 in the surgical management of pyogenic spinal infections: a focused review[J/OL]. Eur Spine J. 2025;34(10):4631–7. 10.1007/s00586-025-08993-9. <https://pubmed.ncbi.nlm.nih.gov/40504240/>.
10. MEDINA A V, ORTIZ G M OJEDAS, E, . World Neurosurg. 2024;187:e28–34. 10.1016/j.wneu.2024.03.047. <https://pubmed.ncbi.nlm.nih.gov/38508383/>. Use of Recombinant Human Bone Morphogenetic Protein-2 After Anterior Cervical Corpectomy and Fusion for the Treatment of Vertebral Osteomyelitis[J/OL].

11. Yang HQ, Zhang YH, Li Q, Zhang HY, Zhao DZ, Han QH, Yang Y, Yang QC, Qu L. [NRD assisted Ilizarov technique in the treatment of infected bone and soft tissue defect of tibia]. *Zhongguo Gu Shang*. 2022;35(10):921-6. Chinese. 10.12200/j.issn.1003-0034.2022.10.004. PMID: 36280407.
12. Sun X, Song J, Zhao X, Zhang Z, Sun J. Limb-saving integrative Chinese-western therapy for necrotizing fasciitis: A case report and literature review. *Explore (NY)*. 2025 Nov-Dec;21(6):103275. 10.1016/j.explore.2025.103275. Epub 2025 Oct 24. PMID: 41175717.
13. Lei T, Guo J, Wang P, Zhang Z, Niu S, Zhang Q, Qing Y. Establishment and Validation of Predictive Model of Tophus in Gout Patients. *J Clin Med*. 2023;12(5):1755. 10.3390/jcm12051755. . PMID: 36902542; PMCID: PMC10002994.
14. Zyluk A, Flicinski F. Gouty Tophus of a Flexor Tendon at the Level of the Wrist. *Handchir Mikrochir Plast Chir*. 2023;55(1):73–4. 10.1055/a-1691-9892. English.
15. Embaby OM, Elalfy MM. First metatarsophalangeal joint: Embryology, anatomy and biomechanics. *World J Orthop*. 2025;16(4):102506. 10.5312/wjo.v16.i4.102506. . PMID: 40290610; PMCID: PMC12019138.
16. LEE, SJ,NAN KL,JIN, HM, et al. Bone destruction by receptor activator of nuclear factor kappa ligand-expressing T cells in chronic gouty arthritis[J]. *Arthritis Res Ther*. 2011;13(5):164.
17. Buruian A, Angelo S, Seica E, Fernandes F, Mendes A. Advanced Erosive Gouty Arthropathy of the Knee. *Cureus*. 2024;16(1):e51432. 10.7759/cureus.51432. . PMID: 38298291; PMCID: PMC10828979.
18. Korsun MK, Asada T, Hirase T, Zhang B, Kwas CT, Zhang J, Kim ET, Morse KW, Sandhu HS, Kim HJ, Cunningham ME, Albert TJ, Huang RC, Dowdell JE, Farmer JC, Lovecchio FC, Sheha E, Iyer S, Qureshi SA. Current Use and Complications Associated With Bone Morphogenetic Protein in Spine Fusion Surgery: A Review of 9809 Patients. *Spine (Phila Pa 1976)*. 2026;51(6):400–7. 10.1097/BRS.0000000000005372. . Epub 2025 Aug 20. PMID: 40833118.
19. Bove A, Braile A, Sirico S, Orabona N, Braile M. A Scoping Review of CERAMENT™ Applications in Orthopedic Surgery. *J Clin Med*. 2025;14(21):7455. 10.3390/jcm14217455. . PMID: 41226852; PMCID: PMC12609670.
20. Yu Y, Chen R, Chen X, Wang J, Liu C. Regulating the bioactivity of non-glycosylated recombinant human bone morphogenetic protein-2 to enhance bone regeneration. *Bioact Mater*. 2024;38:169–80. 10.1016/j.bioactmat.2024.04.018. . PMID: 38711759; PMCID: PMC11070760.
21. Wang M, Xu C, Zheng Y, Pieterse H, Sun Z, Liu Y. In vivo validation of osteoinductivity and biocompatibility of BMP-2 enriched calcium phosphate cement alongside retrospective description of its clinical adverse events. *Int J Implant Dent*. 2024;10(1):47. 10.1186/s40729-024-00567-6. . PMID: 39472366; PMCID: PMC11522231.
22. He L, Wang X, Xiong N, Dong Z, Cheng L. BMP-2 enhanced new bone formation of calcium phosphate-based composites in mice. *Biomed Mater Eng*. 2025;36(6):361–71. 10.1177/09592989251346468.

23. Chernysheva M, Ruchko E, Ereemeev A. Optimizing rhBMP-2 Therapy for Bone Regeneration: From Safety Concerns to Biomaterial-Guided Delivery Systems. *Int J Mol Sci.* 2025;26(21):10723. 10.3390/ijms262110723. . PMID: 41226759; PMCID: PMC12609753.
24. Liu Q, Zheng J, Ma L, Chu D, Yang Z, Niu N, Shi J. Clinical efficacy of allograft bone combined with calcium phosphate bone powder in repairing bone defects of benign bone tumors: A retrospective controlled study. *BMC Surg.* 2025;25(1):99. 10.1186/s12893-025-02823-x. . PMID: 40087717; PMCID: PMC11907860.
25. Li Y, Zhao J, Chen C. Efficacy and safety of recombinant human bone morphogenetic protein-2 biomaterials in promoting bone regeneration: A systematic review and meta-analysis. *Jt Dis Relat Surg.* 2026;37(2):325–43. Epub 2025 Dec 29. PMID: 41906828.
26. Medina AV, Murray Ortiz G, Estronza Ojeda S, de Jesus Espinosa A, Pastrana EA. Use of Recombinant Human Bone Morphogenetic Protein-2 After Anterior Cervical Corpectomy and Fusion for the Treatment of Vertebral Osteomyelitis. *World Neurosurg.* 2024;187:e28–34. Epub 2024 Mar 18. PMID: 38508383.
27. Li P, Ning X, Jia L, Du G, Jiang S, Gong Z, Song K, Wang Z, Zhang K. A minimally invasive incision and loop drainage technique for the treatment of lower limb Morel-Lavallée lesions: Nose ring drainage technique. *Injury.* 2020;51(2):570–3. Epub 2019 Dec 9. PMID: 31852590.
28. Pu S, Xu Y, Lü Q, Liu Z, Zhao Y, Zhao Z, Xia S, Qi X, Qu L, Zhu Y. [Clinical application of nose ring drain technique combined with Ilizarov circular external fixation for Gustilo ⅢA Pilon fractures]. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi.* 2021;35(2):195–199. Chinese. 10.7507/1002-1892.202009101. PMID: 33624473; PMCID: PMC8171683.
29. Shiozaki T, Kimura T, Saito M, Kubota M. Three Cases of Gouty Tophus in the Foot Treated by Resection. *Cureus.* 2023;15(4):e37144. 10.7759/cureus.37144. . PMID: 37153285; PMCID: PMC10160552.
30. He G, Lu S, Lu X, Liu Y. [Comprehensive management of tophaceous wound]. *Zhejiang Da Xue Xue Bao Yi Xue Ban.* 2025;54(5):611–9. 10.3724/zdxbyxb-2025-0159. Chinese.
31. Kumar S, Gow P. A survey of indications, results and complications of surgery for tophaceous gout. *N Z Med J.* 2002;115(1158):U109.
32. FitzGerald JD, Dalbeth N et al. 2020 American College of Rheumatology Guideline for the Management of Gout. *Arthritis Care Res (Hoboken).* 2020;72(6):744–760. 10.1002/acr.24180. Epub 2020 May 11. Erratum in: *Arthritis Care Res (Hoboken).* 2020;72(8):1187. doi: 10.1002/acr.24401. Erratum in: *Arthritis Care Res (Hoboken).* 2021;73(3):458. doi: 10.1002/acr.24566. PMID: 32391934; PMCID: PMC10563586.
33. Kimura T, Kubota M, Hattori H, Saito M. Gouty Tophus in the Foot without Hyperuricemia Diagnosed by Dual-energy Computed Tomography: A Case Report. *J Orthop Case Rep.* 2021;11(10):73–5. 10.13107/jocr.2021.v11.i10.2476. . PMID: 35415087; PMCID: PMC8930302.
34. Pan Y, Lin S, Pan N, Cheng S, Yao J, Liang P, Yan X, Li J, Liang Z, Lin Z, Qiu Z, Bao L, Zhong L, Lin S, Zhan F, Chen Y, Liu B, Luo S, Mi L, Zhu H, Wang G, Lin J, Chen Y, Fu X, Huang Y. CMDA Consensus

Figures



Figure 1

The arrow indicates punched-out bone destruction caused by gouty tophus.



Figure 2

Gross appearance of rhBMP-2-loaded CPC.



Figure 3

Gross appearance of the nose ring drain (NRD) after gouty tophus surgery.

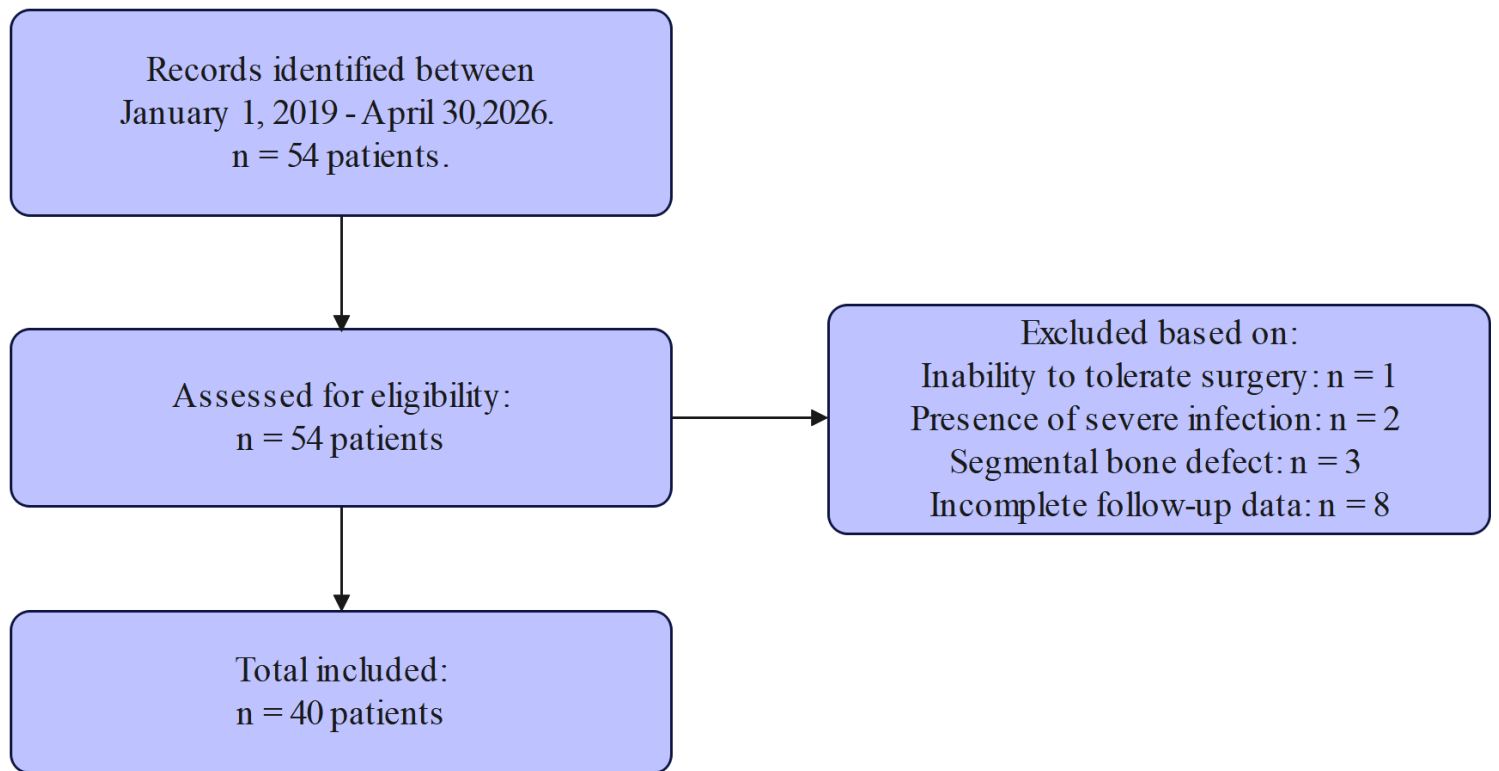


Figure 4

Flowchart illustrating the inclusion of the study population.